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(56) Documents Cited
GB 2271648 A GB 2222696 A GB 2215078 A
GB 2151066 A GB 2133574 A EP 0467601 A
EP 0393709 A

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(54) Abstract Title
Producing holographic patterns

(57) Holographic patterns are produced by utilising a laser 10, preferably pulsed of 10 nanoseconds or less, to illuminate a workpiece 21 with an interference pattern at a spot 21a. Sufficient laser power is used so as to ablate the workpiece 21 where it is illuminated by the laser. The workpiece 21 is mounted on a movable table 22 so that it can be moved relative to the interference pattern using stepping motors 24a, 24b for movement in X and Y directions. In a further embodiment (Fig 2 not shown) the workpiece is cylindrical and may be rotated and axially translated in order to move the workpiece relative to the interference pattern.

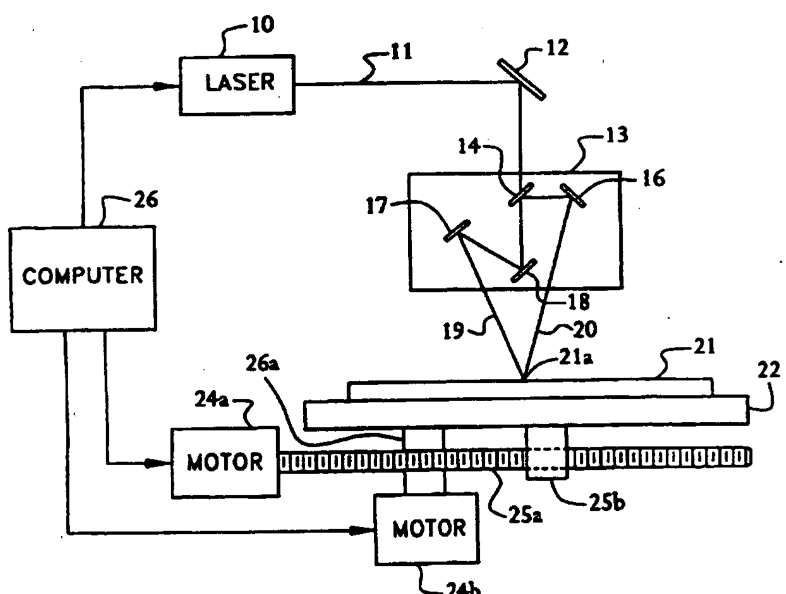

FIG. 1

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

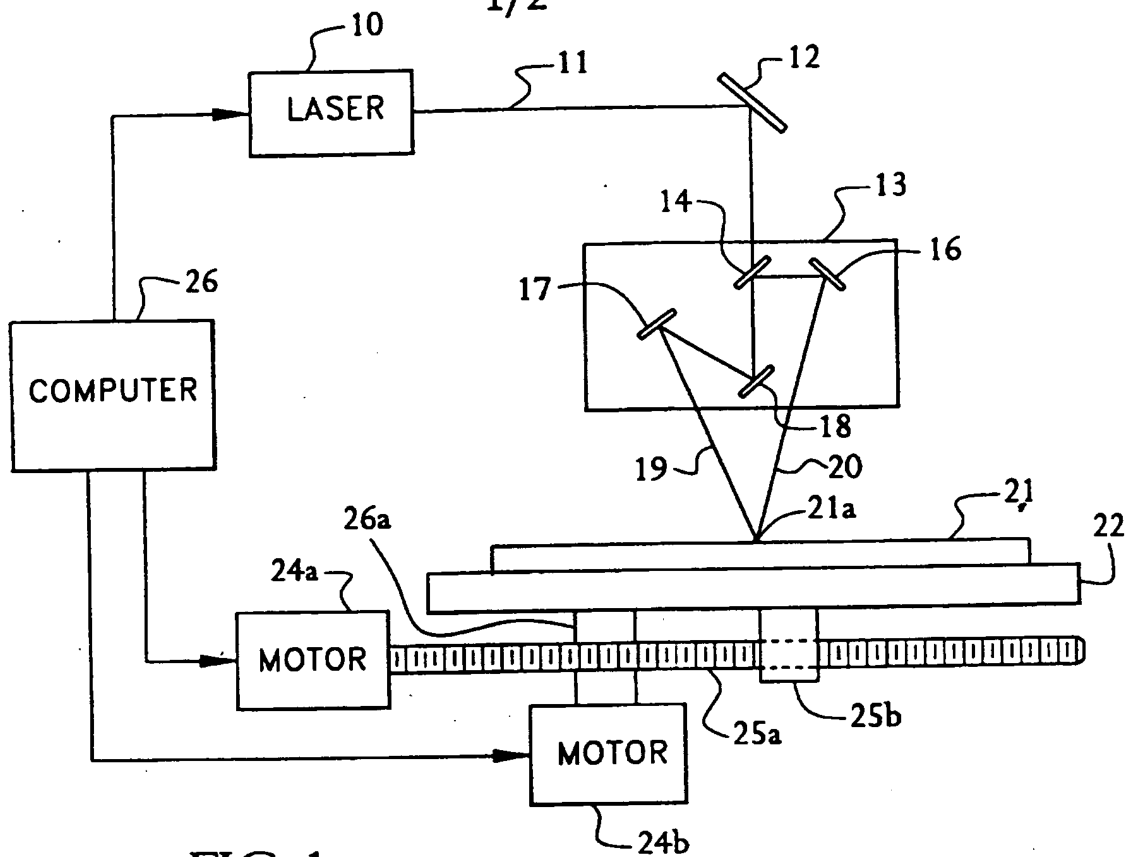

FIG. 1

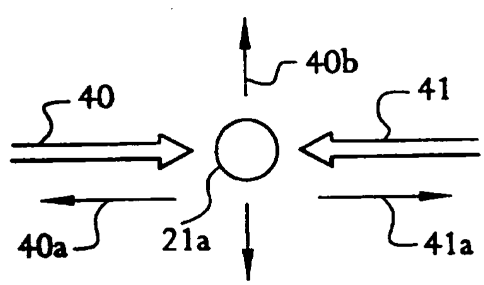

FIG. 3

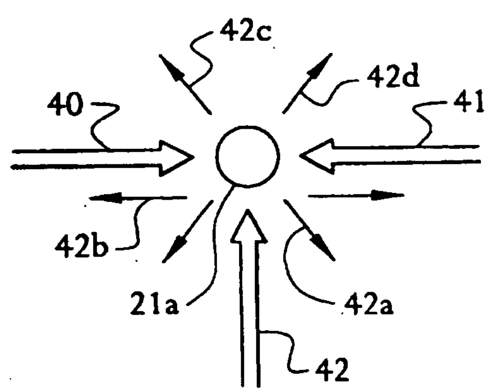

FIG. 4

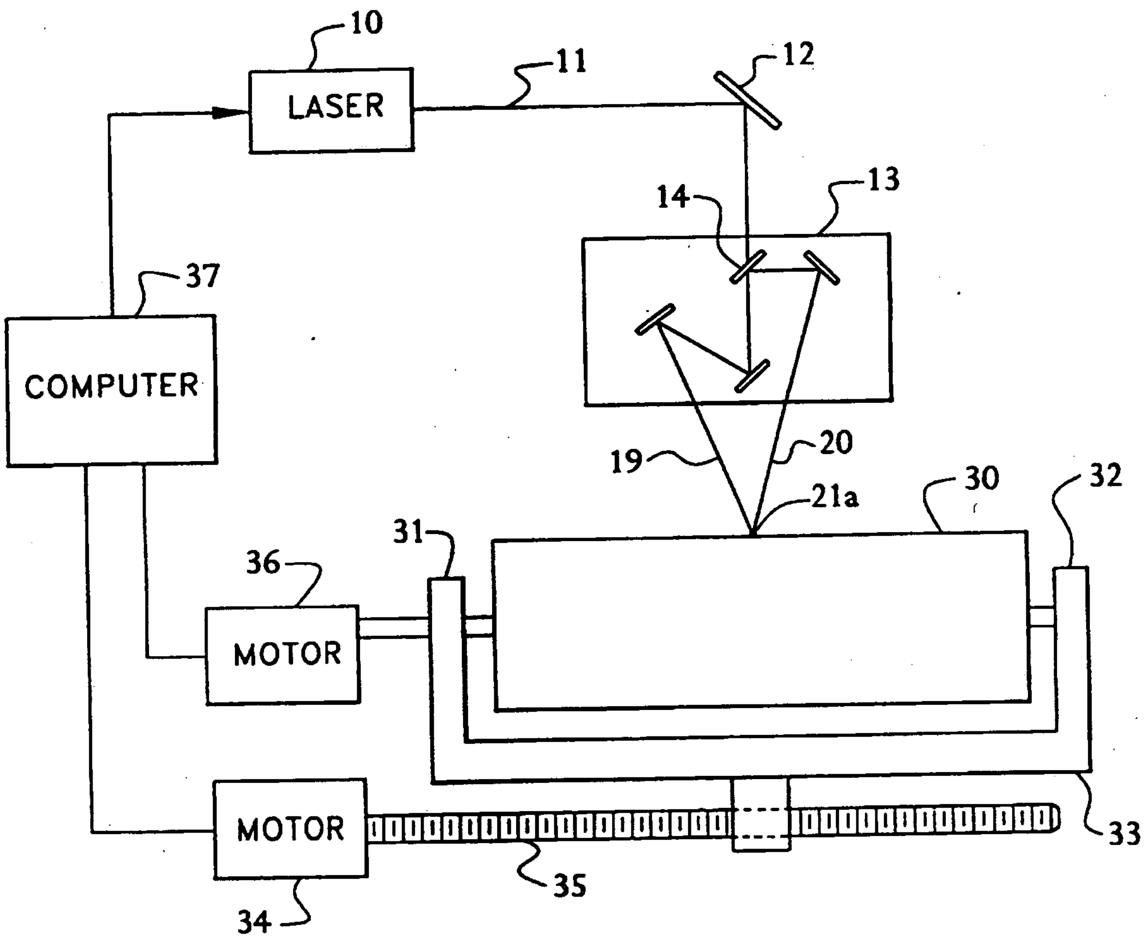
10
LASER
11
12
13
14
37
COMPUTER
19
20
21a
30
32
31
36
MOTOR
MOTOR
33
35
34

FIG. 2

HOLOGRAPHY APPARATUS, METHOD AND PRODUCT

The present invention relates to a technique for producing holographic patterns and more particularly to the apparatus and method for practicing this technique and the products which result.

It is known to use interferometry to expose light sensitive material (photoresist) so as to harden that material in specific locations. When the unhardened portions are removed, the remaining material forms patterns of lands and grooves which correspond to interference patterns and which can therefore be used to produce holographic products. To that end, the patterns initially formed in the photoresist are processed so that they can then be embossed in metal or plastic. The resulting embossings are used as shims for transferring these patterns onto the final holographic product, such as sheets of paper, plastic film, or the like.

In performing the initial exposure, the interferometric illumination had to remain stationary at each desired location for a sufficient period to harden the photoresist at that location. The illumination would then be moved to the next location and the exposure repeated there. This movement was accomplished by appropriately displacing the interferometer "head", or the substrate bearing the photoresist. The required dwell time at any particular exposure location was of the order of magnitude of 1 millisecond.

Unfortunately, a dwell time of that duration was frequently incompatible with unintentional displacements of the interferometer head and/or the photoresist-bearing substrate. Such unintentional displacements can be caused by environmental factors, such as vibrations induced by the nearby passage of vehicles, or by other vibration-producing equipment. They can also be caused by the functioning of the exposure-producing equipment itself. Specifically, since the displacement between consecutive photoresist exposure locations took place intermittently, between exposure at one location and the next, the starting and stopping of this intermittent displacement, in itself, gave rise to vibrations in the equipment. As a result, the stationary dwelling of the illumination at each location was compromised and the resulting interference pattern was degraded. In turn, this also caused degradation of the holographic effects in the end product.

In practice, even vibrations of small amplitude could lead to serious degradation, because of the high degree of positional precision required to achieve correct interferometric exposures.

Efforts to overcome this problem by using more massive photoresist supports, or more firmly mounted interferometer heads not only led to unwanted complexity, but were sometimes counterproductive. Thus, the more massive the supports, the more difficult it became to displace them without inducing increased start-stop vibrations.

The same problems also tended to limit the size of the surface on which the initial exposures could be performed. In turn, this meant that large holographic surfaces had to be

built up from multiple small surfaces placed side-by-side. That caused the appearance, in the final holographic product, of seams which are considered visually objectionable.

Accordingly, it is an object of the present invention to overcome one or more of the problems described above.

It is another object to provide a technique for producing holographic products which is less subject than the prior art to vibration problems.

It is still another object to produce holographic products which are free of seams over substantially larger areas than heretofore.

These and other objects which will appear are achieved as follows.

In accordance with the present invention, a pulsed laser beam is projected interferometrically onto a workpiece, so as to consecutively form interference patterns on selected spots of that workpiece. The beam intensity and the workpiece material are so chosen that this material is ablated in lines which correspond to the illuminated lines of the laser interference pattern. The workpiece and laser beam are displaced relative to each other, so that the consecutive spots are formed at different locations on the workpiece. In this way, there is formed on the workpiece a set of ablation patterns which collectively correspond to a desired overall holographic pattern, or holographic imagery. We have found that the pulsed laser projection on each individual spot can be of extremely short duration, so short that any displacement

of that spot on the workpiece due to vibration of either that workpiece or the laser, or both, will be too small to appreciably degrade the interference pattern created at that spot. Indeed, we have discovered that it is even possible to intentionally keep the workpiece and the laser in continuous movement relative to each other, and still create no appreciable degradation of the resulting interference patterns and therefore also no degradation of the ultimate holographic product.

Accordingly, our technique has numerous advantages over the prior art.

In our technique, the laser pulses can have a duration of the order of 6 to 10 nanoseconds, which is some 100,000 times shorter than the 1 milliseconds exposure previously used for photoresists. Obviously, no appreciable displacement of workpiece relative to laser beam can take place during such a period of only a few nanoseconds. Consequently, our technique does not suffer from degradation due to vibration effects and can be applied to large surfaces. Our technique does not necessarily require intermittent, start-stop movements of the workpiece relative to the laser beam, but can be carried out with continuous relative movement. Our technique operates more rapidly, since the much longer exposure times required for photoresists are essentially eliminated, and our technique also does not require the chemicals and "wet chemistry" involved in using photoresists.

For further details, reference is made to the discussion which follows, taken in light of the accompanying drawings wherein

Figure 1 is a simplified diagrammatic illustration of an embodiment of the present invention;

Figure 2 is a similarly simplified diagrammatic illustration of another embodiment of the invention; and

Figures 3 and **4** are diagrams which will assist in explaining certain features of the invention.

The same reference numerals are used in the several figures to denote corresponding elements.

Referring to **Figure 1**, this shows a laser **10** which is adapted to emit a pulsed laser beam **11**. A mirror **12** deflects beam **11** toward an interferometer head **13**. Head **13** includes a beam-splitting mirror **14** and a set of three additional mirrors **16**, **17** and **18** for directing the split beams **19** and **20** toward a workpiece **21**, in such relative angular orientations as to create the desired interference pattern at a spot **21a** on that workpiece **21**.

Workpiece **21** is mounted on a moveable table **22**. Reversible stepper motors **24a** and **24b** are provided for displacing table **22** step-wise in two mutually perpendicular directions, both parallel to the surface of workpiece **21**. Motor **24a** drives table **22** selectively to the right or to the left in **Figure 1**. Motor **24b** drives table **22** selectively into or out of the plane of the paper in **Figure 1**. These movements are transmitted from the respective stepper motor to the table **22** by mutually perpendicular lead screws to which table **22** is driveably connected. In **Figure 1**, there are visible the right-

left lead screw **25a** and internally threaded sleeve **25b** which connects lead screw **25a** to table **22**. The in-and-out lead screw is not visible in **Figure 1** because it is hidden behind motor **24b**; only its connection **26a** to table **22** is visible in that figure.

A computer **26** controls the stepping operations of motors **24a** and **24b** and the pulsing of laser **10** in the following manner.

The table **22**, and with it workpiece **21**, are displaced in small incremental steps. At the end of each predetermined number of steps, during the stop which forms part of the last of these steps, the laser **10** is pulsed so that a spot **21a** on workpiece **21** is interferometrically illuminated, and a land-and-groove pattern is formed through ablations which correspond to the interference pattern produced at that spot.

Typically, motor **24a**, through lead screw **25a**, will cause table **22** (and workpiece **21**) to move the full length of that workpiece, e.g. from left to right in **Figure 1**, while laser **10** is pulsed as described above. Motor **24b**, through its in-and-out lead screw (not visible in **Figure 1**), will then move the table and workpiece by the width of one spot at right angles to the preceding movement, e.g. into the plane of the paper in **Figure 1**. Motor **24a** then moves the table and workpiece back in the opposite direction from before, i.e. from right to left, and so on repeatedly until as much of workpiece **21** as desired is covered by the spots of ablation-produced patterns.

After this process has been carried to completion, workpiece **21** is used as the "master" for embossing corresponding patterns, either directly into the final

holographic product, or into intermediate "shims" which are then used in turn to emboss these patterns into the final product.

Laser **10** is preferably a so-called YAG (yttrium arsenic garnet) laser. We have found that, surprisingly, very brief illumination with such a laser is sufficient to produce the desired ablation of the workpiece **21**. That workpiece may be made of any material capable of being so ablated. Specific materials which have been found suitable are plastics, such as polyimides and aminimides. For example, sheets of Kapton, which is a polyimide material commercially available from the Dupont Company, Wilmington, Delaware, have been found suitable as workpiece **21**.

Due to the freedom from vibration problems, such holographically patterned sheets can be produced with dimensions up to 32 X 42 inches, which is a standard size for current conventional equipment used for subsequent processing. However, even larger sheets are expected to be producible by the present invention. In the prior art, products of such size could be made only by piecing together several smaller sheets, with the attendant objectionable seam lines.

The technique of the present invention is not limited to use with flat workpieces such as shown in **Figure 1**. Rather, it can be applied to other workpiece configurations, such as the cylindrical form shown in **Figure 2**, to which reference may now be had.

In **Figure 2**, a cylindrical workpiece **30** is provided in the form of a sheet, or a surface coating on a cylindrical substrate. Cylinder **30** is mounted in bearings **31**, **32** for

rotation about its axis and also, by means of cradle **33**, for translation parallel to its axis. As in **Figure 1**, a laser **10** produces a beam **11**, which is projected interferometrically on workpiece **30**. A stepper motor **34** and associated lead screw **35** are provided to translate cradle **33** axially with respect to cylinder **30**. Another stepper motor **36** is connected to the cylinder to provide rotation about its axis. A computer **37** coordinates the movements of the cylinder and the pulsing of laser **10**.

A variety of patterns of cylinder movements and laser pulses can be used. For example, the cradle **33** can be moved alternately from left to right and from right to left, while the cylinder **30** is rotated by one width of spot **21a** at the end of each such movement. In this way, an overall pattern is built up on workpiece **30** which consists of axial rows of spots **21a** displaced circumferentially around the cylinder.

Alternatively, the cylinder **30** can be moved axially from one end to the other, while also rotating it during that axial movement. By performing these movements at the appropriate relative rates, there is formed a pattern of spiral lines of spots **21a** around the workpiece **30**.

The stepper motors previously mentioned in relation to **Figures 1** and **2** operate at very high rates of stepping frequency. For example, they may produce 375,000 step movements per inch of overall displacement. The laser associated with these embodiments may then be pulsed so as to produce an illuminated spot **21a** every 1,875 steps, i.e. 200 times per inch. The step movement occurs in so many small increments per unit length of movement that it is virtually

continuous. The reason for preferring steps to true continuous movement is that the former lends itself to convenient digital control of the relationship between movement and laser pulsing. Alternatively true continuous movement may be used.

Whether intermittent or continuous, a workpiece movement speed of about 2" per second has been found suitable, using a YAG laser's third harmonic as the beam source. As for spot size, 125 microns has been found suitable. Other values can, of course, be used as appropriate.

The remaining processing of the workpieces treated in accordance with the invention may be done in known manner, for example, as disclosed in U.S. Patent No. 5,706,106; issued January 6, 1998.

It will be understood that the inventive technique is not limited to producing the specific over-all patterns described. Rather, by appropriate programming of the computers **26** and **37** any of a variety of spot patterns can be produced.

Also, the individual spots **21a** need not all have the same interference patterns and consequent holographic effects. It is known that holographic patterns create different visual effects depending upon the azimuthal orientation of the land-and-groove patterns which produce the holographic effect. Accordingly, means can be provided for changing the azimuthal orientation of the interferometer head **13** shown in **Figures 1** and **2** from time to time. This will correspondingly change the orientation of the interference patterns on the workpiece. In this way, visually distinctive regions, or "imagery" can be incorporated in the overall holographic pattern. These changes

can be programmed into the respective computer so as to take place automatically during the exposure process.

The appearance of the holographic patterns produced in accordance with the present invention can also be changed by changing the included angle between the two split beams **19** and **20** (**Figures 1** and **2**) as these approach and impinge upon the workpiece. Such changes change the spatial frequency of the interference pattern created by the beams on the workpiece. Such changes in included angle can be accomplished by piezoelectric control of the angular positions of the mirrors which direct these split beams **19** and **20** onto the workpiece.

We have also found that changes in the power level of the laser beam can effect changes in the size of spot **21a**, and this also produces changes in the holographic effect.

It is also known that a holographic pattern produced by two split beams, as in the case of **Figures 1** and **2**, will produce a visual holographic effect primarily in one viewing plane. This effect diminishes as the viewing direction deviates in azimuth, reaching a minimum at right angles to the maximum. Yet, it is frequently desirable to provide holographic effects which are more uniform in azimuth. This can readily be accomplished by the inventive technique.

Figure 3 shows the azimuth orientations **40** and **41** from which the split beams **19** and **20** of **Figures 1** and **2** are projected onto their respective workpieces and spots **21a**. These orientations yield a spot **21a** which creates a maximum holographic effect in the directions **40a** and **41a**. The effect is at a minimum in the intermediate directions **40b** and **41b**.

Figure 4 shows how the effect can be made azimuthally more uniform. To that end, there is generated a third split beam at orientation **42**, which is projected on spot **21a** at an azimuthal orientation midway between orientations **40** and **41**. This additional beam interacts with the beams in orientations **40** and **41** to produce four additional maximal viewing directions **42a, b, c** and **d**. In this way, the azimuthal variations between maximum to minimum holographic effects are substantially reduced.

To obtain such a third split beam **42**, the two split beams (**19** and **20** in **Figures 1** and **2**) obtained by the single beam-splitting mirror **14** would each have to be split a second time, at right angles to the first split, with only 3 of the resulting 4 split beams projected onto the workpiece.

Of course, other azimuthal relationships between split beam orientations can also be used, e.g. 3 beams azimuthally oriented at 120° from each other.

It will be understood that other modifications will occur to those skilled in the art without departing from the inventive concepts. For example, interferometer head **13** can be moved in lieu of the workpiece to produce the patterns of spots **21a**, or even both the head and the workpiece. However, such movement of head **13** would be a more delicate operation and is therefore not preferred. Accordingly, it is desired to limit the inventive concept only by the appended claims.

CLAIMS

1. A method of producing a holographic pattern, comprising the steps of:

utilizing a laser to illuminate a workpiece with an interference pattern, said laser having sufficient power to ablate said workpiece where illuminated by said laser, and

producing relative movement of said workpiece and said interference pattern.

2. The method of claim 1 wherein said laser illumination and resulting ablation are produced intermittently.

3. The method of claim 2 wherein said workpiece movement and laser illumination are coordinated so that different portions of said workpiece are illuminated by consecutive ones of said intermittent illuminations.

4. The method of claim 3 wherein said workpiece is substantially flat and its movement takes place in mutually perpendicular directions parallel to the workpiece.

5. The method of claim 3 wherein said workpiece is substantially cylindrical and its movement takes place parallel to the cylinder axis and circumferentially around the axis.

6. The method of claim 3, wherein at least some portions of said workpiece are illuminated by laser interference patterns in a plurality of different orientations.

7. The method of claim 6 wherein said laser illuminations in different orientations are produced consecutively.

8. The method of claim 6 wherein said laser illuminations in different orientations are produced simultaneously.

9. The method of claim 1 wherein said laser is a YAG laser.

10. The method of claim 1 wherein said workpiece is a layer of polyimides, or aminimides on a supporting substrate.

11. The method of claim 2 wherein each said intermittent laser illumination is produced during a period sufficiently brief that no substantial relative movement of said workpiece and said pattern can have taken place.

12. The method of claim 11 wherein said period is less than about 10 nanoseconds.

13. Apparatus for producing a holographic pattern, comprising:

a laser;

a workpiece adapted to be illuminated by said laser;

means for utilizing said laser to illuminate said workpiece with an interference pattern, said illumination being sufficiently powerful to ablate said workpiece where illuminated by said pattern; and

means for producing relative movement between said workpiece and said interference pattern.

14. A holographic pattern produced in said workpiece by the method of claim 1.

15. A holographic pattern produced in said workpiece by the method of claim 2.

16. The method of claim 11 which further comprises transferring said holographic pattern from said workpiece to a web.

17. The method of claim 16 where said web is formed by a roll of paper or plastic.

18. The method of claim 16 wherein said web is in sheet form.

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Application No:	GB 9902300.4	**Examiner:**	Meredith Reynolds
Claims searched:	1-18	**Date of search:**	8 July 1999

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): G2J (J33BX, J33B3)

Int Cl (Ed.6): G03H 1/04

Other: Online: WPI, EPODOC, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB 2271648A	(Holtronic)(whole doc, esp pp 11-13)	1-3,5,13-15
X	GB 2222696A	(Exitech)(whole doc, esp p 2 lines 13-25)	1,10-14
X	GB 2215078A	(EEV Co)(whole doc, esp p 4)	1-4,11,13-15
X	GB 2151066A	(Ley)(whole doc, esp p 4 line 123- p 5 line 15)	1-3,5,13-14
X	GB2133574A	(Applied Holographics)(whole doc, esp Claim 6 and p 4 lines 40-52)	1-4,11-15
X	EP 0467601A	("")(whole doc, esp Figs 2-3, Col 5 lines 4-17)	1-4,6-7,13-15
X	EP 0393709A	(du Pont)(whole doc)	1-3,5,13-14

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.